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DEVELOPMENT OF A HEAT SEALED PACKAGING SYSTEM FOR FROZEN AND RE--ETC(U)
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TECHNOLOGY INCORPORATED
LIFE SCIENCES DIVISION

DEVELOPMENT OF A HEAT SEALED PACKAGING SYSTEM

FOR FROZEN AND REFRIGERATED FOODS

CONTRACT F41609-75-C-0016

FINAL REPORT

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17311 EL CAMINO REAL • HOUSTON, TEXAS 77058

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS AEROSPACE MEDICAL DIVISION (AFSC)
BROOKS AIR FORCE BASE, TEXAS 78235

REPLY TO ATTN OF: RDX

4 June 1979

SUBJECT: Request for Scientific and Technical Reports (your ltr 24 May 79)

TO: DDC-DDA-1/B7-0444
Cameron Station
Alexandria, VA 22314

1. Attached is one (1) copy of final report, Development of a Heat Sealed Packaging System for Frozen and Refrigerated Foods, Contract F41609-75-C-0016. Two copies of report were forwarded shortly after completion of effort in 1975; however, due to termination of mission, records have been sent to the repository and are not available to permit identification of exact date.

2. The report contains no classified or sensitive information and has been cleared for public release.

Joseph C. Crigler

J. C. CRIGLER, Major, USAF BSC
Chief, Technical Plans and Analysis Division
Directorate of Research and Development

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Report - Technology Incorporated, Life Sciences Div.

[redacted]

TECHNOLOGY INCORPORATED

LIFE SCIENCES DIVISION

HOUSTON, TEXAS

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6 DEVELOPMENT OF A HEAT SEALED PACKAGING SYSTEM FOR FROZEN AND REFRIGERATED FOODS.

CONTRACT 15 F41609-75-C-0016

9 FINAL REPORT.

11 1975

APPROVED BY:

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General Manager

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Table of Contents

List of Tables

ABSTRACT

This final report is submitted in compliance with Contract F-41609-75-C-0016, "Development of a Heat Sealed Packaging System for Frozen and Refrigerated Foods." The state of the art for material compatibility for heat sealed packaging systems for frozen and refrigerated foods was reviewed and summarized. Appropriate literature was reviewed. Producers, supplier and users of packaging materials were contacted to obtain information on new and currently available materials and concepts. Trade-off analyses were conducted to identify optimum materials which would be compatible with frozen temperatures and microwave and convection oven temperatures (300°F+).

DEVELOPMENT OF A HEAT SEALED PACKAGING SYSTEM
FOR FROZEN AND REFRIGERATED FOODS

INTRODUCTION

The purpose of the project was to determine the current state of the art in frozen food packaging and subsequent heating utilizing microwave and convection heating methods. The state of the art was assessed by a literature review and by direct contact with producers, suppliers and users of packaging materials.

The project was initiated by examining the Modern Plastics Encyclopedia where primary nonmetallic polymer material screening began. The primary objective was the identification of commercially available materials which had compatible physical properties. Those materials qualifying for further examination had to comply with FDA requirements and had to maintain, to a degree, physical integrity at sub -40° temperatures. Physical property data of these materials were then gathered and applied in a trade-off analysis. Materials qualifying as acceptable for product reconstitution in either microwave or convection ovens were so grouped and ranked. Materials qualifying only for microwave reconstitution were accordingly grouped and ranked.

In support of the material trade-off analysis and in order to determine the present state of the art in frozen food packaging, a telephone survey was conducted to obtain additional information. Respondents of

this survey represented material producers and suppliers and frozen food producers. This survey provided new information besides supplementing and supporting previously established data.

The following report contains two sections. The first section contains the nonmetallic polymeric material trade-off study as evaluated from physical property data. Within this section, a discussion of the evaluation format, a review of the physical property data and summary of results are offered as guides for future frozen food packaging material selection. The second section contains information on packaging materials which are currently being used by the frozen food industry, and what is projected for future use. Within this section of the report, the results of the survey are discussed and include a summary of current and future concepts, design, and expected trends. This section contains information on the extent of interchangeability permitted by commercially available containers based on size and sealing ability employing a single packaging machine.

Recommendations as to which two combinations of containers and heat sealable lidding material for each category (metallic and nonmetallic) will provide the best total food package is also included.

SECTION I

NONMETALLIC POLYMERIC MATERIAL TRADE-OFF STUDY

I. NONMETALLIC POLYMERIC MATERIALS TRADE-OFF STUDY

This section contains the nonmetallic polymeric trade-off study. The study was initially conducted on all polymers which met with FDA approval and maintained, to a degree, physical integrity at sub -40°F temperatures. Explanation of the trade-off scoring criteria is provided in Appendix "A". The evaluated materials are divided into two categories. The first category contains those materials which can withstand the physical and thermal parameters inherent with both microwave and convection oven food preparation. The second category contains those materials which may be subjected to only microwave use. The primary criteria is resistance to thermal conditions between 185° and 300°F. Tabulated results are included in Table I. An overall ranking by weighted score as described in Appendix "A" is illustrated in Table II. Physical property data used in this trade-off study is available in Table III.

A. Microwave and Convection Oven Acceptable Nonmetallic Polymer Materials (300°F+)

Materials qualifying as acceptable for convection oven use are Polyester, Nylon 6, TFE, FEP, and Polysulfone (Table IV). All five materials have good thermal resistance properties at -40°F and in excess of the minimum established temperature of 300°F. Due to their nonmetallic composition, these material are also acceptable for microwave oven usage. The following paragraphs contain descriptive information for these materials.

TABLE I

MICROWAVE ACCEPTABLE, FDA APPROVED NONMETALLIC POLYMER MATERIALS-(185-299°F)

	I	II	III	IV	V	VI	VII	TOTAL	HEAT °F
WEIGHTING FACTOR	7	7	7	7	4	4	2		
1. PP-B.O.C.	5	5	5	4	5	5	5	183	290
	35	35	35	28	20	20	10		
2. PP-B.O.	5	5	1	4	5	5	5	155	290
	35	35	7	28	20	20	10		
3. NYLON 12	5	3	1	5	5	4	4	142	218
	35	21	7	35	20	16	8		
4. HDPE	5	5	1	4	4	3	3	139	250
	35	35	7	28	16	12	6		
5. NYLON 11	5	3	1	4	5	4	4	135	250
	35	21	7	28	20	16	8		
6. MDPE	5	5	1	4	3	3	3	135	220
	35	35	7	28	12	12	6		
7. NYLON 6/6	5	1	4	2	5	5	5	134	250
	35	7	28	14	20	20	10		
8. POLYESTER (PCDT)	5	5	1	2	4	4	4	131	185
	35	35	7	14	16	16	8		
9. PS	5	5	1	1	5	4	4	128	190
	35	35	7	7	20	16	8		
10. LDPE	5	5	1	3	3	2	3	124	190
	35	35	7	21	12	8	6		
11. PTFCE (KEL-F)	5	1	1	5	4	3	4	120	275
	35	7	7	35	16	12	8		
12. POLYCARBONATE (LEXAN)	5	1	1	1	4	3	4	92	270
	35	7	7	7	16	12	8		
13. ABS	3	1	1	1	4	3	4	78	205
	21	7	7	7	16	12	8		

TABLE II

PHYSICAL PROPERTY TRADE-OFF DATA
FOR FDA APPROVED NONMETALLIC POLYMER MATERIALS

	I	II	III	IV	V	VI	VII	VIII	TOTAL
WEIGHTING FACTOR	7	7	7	7	4	4	2	2	
1. PP-B.O.C.	5	5	5	4	5	5	5	3	183
	35	35	35	28	20	20	10	6	
2. PP-B.O.	5	5	1	4	5	5	5	3	155
	35	35	7	28	20	20	10	6	
3. POLYESTER	5	3	3	2	5	5	5	5	141
	35	21	21	14	14	20	20	10	
4. NYLON 12	5	3	1	5	5	4	4	3	142
	35	21	7	35	20	16	8	6	
5. HDPE	5	5	1	4	4	3	3	3	139
	35	35	7	28	16	12	6	6	
6. NYLON 11	5	3	1	4	5	4	4	3	135
	35	21	7	28	20	16	8	6	
7. MDPE	5	5	1	4	3	3	3	3	135
	35	35	7	28	12	12	6	6	
8. NYLON 6/6	5	1	4	2	5	5	5	3	134
	35	7	28	14	20	20	10	6	
9. POLYESTER (PCDT)	5	5	1	2	4	4	4	1	131
	35	35	7	14	16	16	8	2	
10. NYLON 6	5	1	4	1	5	4	4	5	121
	35	7	28	7	20	16	8	10	
11. P.S.	5	5	1	1	5	4	4	1	128
	35	35	7	7	20	16	8	2	
12. PTFCE (KEL-F)	5	1	1	5	4	3	4	3	120
	35	7	7	35	16	12	8	6	
13. LDPE	5	5	1	3	3	2	3	1	124
	35	35	7	21	12	8	6	2	
14. EVA	5	5	1	2	3	2	3	1	119
	35	35	7	14	12	8	6	2	
15. TFE(TEFLON)	5	1	1	4	4	3	3	5	111
	35	7	7	28	16	12	6	10	
16. FEP	5	1	1	4	3	2	3	5	103
	35	7	7	28	12	8	6	10	
17. POLYSULFONE	5	1	1	1	5	4	4	5	100
	35	7	7	7	20	16	8	10	
18. IONOMER (SURULYN)	5	3	1	2	4	2	3	1	109
	35	21	7	14	16	8	6	2	
19. POLYCARBON-ATE (LEXAN)	5	1	1	1	4	3	4	3	92
	35	7	7	7	16	12	8	6	
20. ABS	3	1	1	1	4	3	4	3	78
	21	7	7	7	16	12	8	6	

TABLE II (CONTINUED)

PHYSICAL PROPERTY TRADE-OFF DATA FOR FDA APPROVED NONMETALLIC POLYMER MATERIALS

	I	II	III	IV	V	VI	VII	VIII	TOTAL
WEIGHTING FACTOR	7	7	7	7	4	4	2	2	
21. CELL. ACET	0	3	1	1	5	4	5	1	83
	0	21	7	7	20	16	10	2	
22. HIGH BARRIER	0	5	5	2	5	4	5	1	132
NITRILE RESIN	0	35	35	14	20	16	10	2	
23. PP-EXT.	0	5	1	4	4	3	4	3	112
	0	35	7	28	16	12	8	6	
24. PVC-N.P.	0	3	1	3	4	3	5	1	89
	0	21	7	21	16	12	10	2	
25. PVDC/VC	0	5	4	4	5	3	3	3	135
	0	35	28	28	20	12	6	6	
26. VC/VA N.P.		5	1	2	4	3	4		No
		35	7	14	16	12	8		
27. VC/VA P.		5	1	1	4	3		1	No
		35	7	7	16	12		2	

TABLE III

MATERIAL PHYSICAL PROPERTY DATA

MATERIAL	I RESISTANCE TO COLD			II HEAT SEAL TEMPERATURE			III PERMEABILITY OF OXYGEN			IV WATER VAPOR TRANS. RATE			V STRENGTH TENSILE			VI TOUGHNESS		VII STIFFNESS MOD. OF ELAS.			VIII RESISTANCE TO HEAT			% ELONGATION		
	-°F	Avg	Eva	+°F	Avg	Eva	cc	Avg	Eva	g	Avg	Eva	psix10^3	Avg	Eva		Eva	10^5	Avg	Eva	°F	Avg	Eva		Avg	Eva
1. ABS	40	40	3	U.S.	-	1	50-70	60	1	15.5-18.3	17	1	5-10	7.5	4	M	3	2.3-3.8	3	4	190-220	205	3	10-50	30	L
2. CELL. ACET.	15	15	0	350-450	400	3	117-150	134	1	20-80	50	1	7-16	11.5	5	G	4	3-6	4.5	5	150-200	175	1	15-70	42	L
3. FEP	425	425	5	540-700	620	1	750	750	1	.4	.4	4	2.5-3	2.75	3	F	2	0.5	.5	3	440-525	483	5	300	300	H
4. PTFCE	320	320	5	450-500	475	1	7-15	11	1	.025-.055	.04	5	5-10	7.5	4	M	3	1.5-3	2.2	4	250-300	275	3	50-150	100	M
5. IONOMER	110	110	5	200-500	350	3	600	600	1	4.1	4.1	2	5	5	4	F	2	0.2-0.6	.4	3	140-160	150	1	250-450	350	H
6. POLYCARB.	150	150	5	400-430	415	1	300	300	1	11.0	11	1	8.4-8.8	8.6	4	M	3	3.0-3.5	3.25	4	270	270	3	85-105	95	M
7. POLYESTER	75	75	5	400	400	3	6-8	7	3	1.7-1.8	1.8	2	6-13	9.5	5	E	5	3.0-6.4	4.7	5	400	400	5	60-165	113	M
8. PCDT	70	70	5	340	340	5	500	500	1	3	3	2	7	7	4	G	4	3	3	4	185	185	1	210	210	H
9. NYLON 6	100	100	5	380-450	415	1	2.6	2.6	4	16-22	19	1	9-18	13.5	5	G	4	2.5-5	3.75	4	200-400	300	5	250-550	400	H
10. NYLON 6/6	60	60	5	460-480	470	1	5	5	4	3-6	5	2	9-12	10.5	5	E	5	4.6	4.6	5	250	250	3	200	200	M
11. NYLON 11	90	90	5	330-367	359	3	34	34	1	.32-.85	.6	4	9-11	10	5	G	4	1.85	1.85	4	200-300	250	3	250-400	325	H
12. NYLON 12	110	110	5	320-380	350	3	52-92	72	1	0.07	.07	5	8.8-12	10.4	5	G	4	1.8	1.8	4	175-260	218	3	290-330	310	H
13. LDPE	70	70	5	250-400	325	5	500	500	1	1.0-1.5	1.3	3	1.5-3	2.25	3	F	2	.14-.38	.25	3	180-200	190	1	100-700	400	H
14. MDPE	70	70	5	250-400	325	5	250-535	393	1	0.7	.7	4	2-3.5	2.75	3	M	3	.25-.55	.4	3	220	220	3	50-650	350	H
15. HDPE	50	50	5	275-400	338	5	185	185	1	0.3	.3	4	2.4-6.1	4.25	4	M	3	.6-1.8	1.2	3	250	250	3	10-650	330	H
16. EVA	76	76	5	150-300	225	5	840	840	1	2-3	3	2	1.5-3	2.25	3	F	2	.02-.12	.07	3	140-180	160	1	500-800	650	H
17. PP-E	0	0	0	285-400	343	5	150-240	195	1	0.7	.7	4	4.5-10	7.25	4	M	3	1.6-2.3	1.95	4	270-300	285	3	550-1000	775	H
18. PP-BO	60	60	5	300-320	310	5	160	160	1	0.25	.25	4	7.5-40	23.7	5	Ex	5	4.5-9	6.75	5	285-295	290	3	35-475	225	H
19. PP-BO-C	60	60	5	190-310	250	5	.9	.9	5	0.25	.25	4	7.5-40	23.7	5	Ex	5	4.5-9	6.75	3	285-295	290	3	35-475	225	H
20. PS	70-94	70	5	250-350	300	5	350	350	1	7-10	9	1	8-12	10	5	G	4	1.4-6	3.7	4	175-205	190	1	3-40	22	L
21. POLYSULFONE	100	100	5	500-550	525	1	230	230	1	18	18		8.4-106	57.2	5	G	4	3.6	3.6	4	350	350	5	64-118	91	M
22. VCA-N.P.	?	0	0	275-360	318	5	15-20	18	1	4	4	2	5.5-8	6.75	4	M	3	3-6	1.8	4	?	0	0	30-80	55	L
23. VCA-P	?	0	0	300-315	308	5	20-150	85	1	5-8	7	1	2.5-5	3.75	4	M	3	?	0	0	150-200	175	1	25-50	38	L
24. PVDC-VC	32	32	0	250-300	275	5	.8-6.9	3.8	4	0.2-0.6	.4	4	8-16	12	5	M	3	1.5-0.8	.65	3	290	290	3	250	250	H
25. PVC-N.P.	10	10	0	350-420	385	3	5-20	13	1	.35-2.0	1.2	3	7-10	8.5	4	M	3	3.5-6	4.75	5	150-200	175	1	3-100	52	L
26. TFE	425	425	5	550	550	1	750	750	1	.4	.4	4	2-5	3.5	4	M	3	.58	.58	3	500	500	5	200-400	300	H
27. BAREX	20	20	0	250	25	5	.8	.8	5	5	5	2	9.5	9.5	5	G	4	4.90	4.90	5	165	165	1	3.5-15	9	L

U.S. Ultrasonic Seal
N.P. Non-plasticized
P.P.B.O.C. Polypropylene, Biaxially Oriented, Coated

F Fair
M Moderate
G Good
Ex Excellent

Permeability of Oxygen cc/100 in^2/mil/24 hrs/atm/@25°C
Water Vapor Trans. Rate g/mil/100 in^2/24 hrs/@37.8°C

TABLE IV

MICROWAVE AND CONVECTION OVEN, ACCEPTABLE NONMETALLIC POLYMER MATERIALS-(300°F+)

WEIGHTING FACTOR	I 7	II 7	III 7	IV 7	V 4	VI 4	VII 2	TOTAL	HEAT °F
1. Polyester	5 35	3 21	3 21	2 14	5 20	5 20	5 10	141	400
2. Nylon 6	5 35	1 7	4 28	1 7	5 20	4 16	4 8	121	300
3. TFE (Teflon)	5 35	1 7	1 7	4 28	4 16	3 12	3 6	111	500
4. FEP (Teflon)	5 35	1 7	1 7	4 28	3 12	2 8	3 6	103	483
5. Polysulfone	5 35	1 7	1 7	1 7	5 20	4 16	4 8	100	350

Polyester

Thermoplastic polyesters currently available are characteristically crystalline thermoplastic resins. Two general types of this material exist. The original and most frequently referred to is polyethylene terephthalate (PET), which is distributed as a film under the trade names of Mylar, Celanar, and Milinex. A second material which has been developed within the past few years is polybutylene Terephthalate (PBT) and is commercially available as G.E.'s Valox Thermoplastic Polyester, Eastman Chemicals' Tenite Polyterephthalate, and Celanese Plastics' Celanex.(1)

Historically, materials constructed of polyester have been considered engineering-type plastics used primarily as automotive accessory parts, electrical connection and insulators. However, today some innovative applications have been designed for use as food packaging material. Polyester is widely used in film laminate construction for flexible pouches. Due to its superior durability characteristics, polyester is primarily employed as a strength and toughness element adding greatly to the integrity of a laminate package, providing protection against physical damage.

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(1) Dr. Morton Kramer, "Thermoplastic Polyester," Modern Plastics Encyclopedia, Oct. '74, pp. 75-76.

Of the five candidate materials, Polyester ranks number one. Although the resistance to heat indicates 400^{o}F, it is felt that available resins, depending upon their precise formulation, will offer a variance in threshhold degradation temperatures.

Du Pont reported recently that they have produced and tested a thermoformable 18 mil polyester container at oven temperatures above 400^{o}F. However, it was further reported that development has been currently suspended due to unfavorable marketing conditions which currently exist.

Nylon 6

Nylon 6 is a member of the polyamine group more specifically identified as polycaprolactum. Nylon 6 is being used in many different industrial and commercial applications. It has been primarily used as an engineering material due to its superior physical properties, thermal, and chemical resistance. Not until recently has Nylon successfully been employed as a food packaging material. This may be attributed to its cost. However, innovations such as "boil-in-the-bag" applications have increased the demand for this material. Of recent entrance and associated with food packaging are the currently available "bake-in-bag" ovenwraps.

Allied Chemical of Morristown, New Jersey, is currently field testing a white pigmented, 17 mil, semi-rigid tray made of a proprietary material called "Capratherm 75." Judging from other Allied

polyamine product trade names, it is only assumed that "Capratherm 75" is possibly a Nylon 6 based material. Reported results from elevated temperature tests of 450°F have satisfied researchers that this product can easily withstand the thermal stress of less than -40°F and in excess of 400°F.

Material property data currently available shows Nylon 6 to possess excellent thermal resistance to temperatures of both extremes (-40°F to 400°F). Although its water vapor transmission rate is high, it possesses good oxygen permeability characteristics along with the toughness parameters of tensile strength and modulus of elasticity.

TFE and FEP (Teflon)

Polytetrafluoroethylene (TFE) is a member of the fluorocarbon family and typically offers material properties which will withstand thermal stress applied below -400° and above 500°F. TFE displays exceptional toughness and flexibility at lower temperatures, a characteristic not dominant in most plastic materials. Generally, TFE is totally insoluble and resistant to attack by corrosive reagents.[(2)] It is a highly crystalline, oriented polymer. TFE is a homopolymer in that it contains polytetrafluoroethylene monomer units exclusively. Fluorinated ethylenepropylene (FEP) is a copolymer which contains

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(2) Fred W. Billmeyer, Textbook of Polymer Science, (New York: Wiley - Interscience, 2 ed. 1971) pp 423-424.

some units of hexafluoropropylene monomer within a molecular chain similar to that of TFE.[3] Its outstanding physical property is again that of thermal resistance to both temperature extremes (-425 to 400^{0}F). It is readily applicable to lamination and, therefore, may be combined with may other materials. With the exception of this molecular deviation, TFE and FEP are quite similar and possess practically the same physical properties as may be seen in Table III. Furthermore, both of these fluoroplastics are marketed by Du Pont as "Teflon."

TFE and FEP are found in many engineering applications involving electrical and electronic circuitry and components, pressure-sensitive tapes. They are found in many other industrial and commercial applications where inertness to chemicals and solvents are manditory prerequisites in addition to nonflammability.[4] Besides possessing excellent thermal characteristics, these materials offer good impermeability against water vapor transmission. However, both materials are currently experiencing limited use in the food packaging industry, and this like nylon may be attributed to high material costs.

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(3) Modern Plastics Encyclopedia, "TFE and FEP", op. cit., p. 39.

(4) Ibid., "Fluoroplastic Film and Sheet," pp 159-160.

Polysulfone

Polysulfone, of the five qualifying materials suitable for convection oven usage, is the only material developed, tested, and commercially available for such diverse use to include microwave food preparation. Union Carbide is currently marketing their polysulfone product under the trade name of "Udel." It resists temperature from below -150°F to over 400°F. It may be thermoformed into single or multiple compartment containers and the engineering properties of this product resist puncturing, wrinkling, and crumpling. Polysulfone has been primarily identifed as an engineering thermoplastic due to its strength and toughness, especially at elevated temperatures of 300°F - 340°F. Containers formed from this material may be conventionally heat sealed with either like material, coated polyester oven film, or coated aluminum foil.[5]

Polysulfones' weak areas are those attributable to barrier properties. Both oxygen permeability and water vapor transmission rates are considered fairly high.

Summary

The ranking of the five materials was conducted by a trade-off analysis involving categories I through VII as previously outlined. Summary information is available in Table IV. A general physical

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(5) "Udel Polysulfone for the Food Service Industry," Union Carbide Produce Information Pamphlet F43846.

property profile of these five materials depict excellent thermal resistance to temperatures below -40°F and in excess of 300°F, good strength and toughness characteristics, and somewhat less favorable gas and water vapor barrier properties. Although barrier properties of these materials are generally poor, this aspect demands clarification.

Barrier properties shown in the data, Table III, are characteristic for a film of 1 mil thickness. The intended application is for a tub of approximately 18 mil thickness. Barrier properties generally display an inverse relationship to material thickness. Additionally, there exists temperature doubling coefficients such that, depending on the material, permeability rates will vary with variance of temperature fluctuations. As an example, Nylon 6 has a doubling temperature for oxygen permeability of 50°F. Therefore, a reduction of 50°F from normal will essentially reduce oxygen permeability by one-half. There exists similar data affecting water vapor transmission rates as well. Therefore, as briefly discussed here, it is evident that barrier properties are dependent on material thickness and storage temperature. Permeability data used in this analysis was in cc/100 in ^{2}/mil/24 hr/atm 77°F.

Although the evaluations were based upon physical property data, consideration to material cost, as previously alluded, cannot be avoided. In order of evaluation, polyester estimate range of

material cost is $1.70 - $3.00 per pound; Nylon 6, $4.00 - $7.00 per pound; TFE and FEP, $12.00 - $35.00 per pound; and polysulfone (Udel) has been quoted at $2.00 per pound.

Using a hypothetical tray of dimension 6 x 4 x 1.5 inches, and of 18 mil material thickness, per unit prices for the five materials are as follows:

Polyester	-	11-12¢/container
Nylon 6	-	20-22¢/container
Polysulfone	-	8-10¢/container
TFE & FEP	-	$1.70-1.90/container

These estimated prices do not include the additional cost of container production, but only material costs for that net amount of material required by the above container.

With the exception of polyester and polysulfone, the material cost exhibited by Nylon 6, TFE and FEP is most probably a prohibitive factor against wider acceptance and application in food packaging.

These materials are essentially considered to be "Engineering Thermoplastics" with commercial and industrial applications involving automotive parts and accessories, hardware components, and electrical and electronic devices and components. With the slight exception of polysulfone, these materials have seen little utilization in food packaging, especially that of one-way, semi-rigid, thermoformable trays and tubs.

B. Microwave Acceptable, FDA Approved Nonmetallic Polymer Materials (185-299°F)

Thirteen nonmetallic, polymer materials have been identified as possessing thermal properties resistant to below -400°F and in excess of 185°F yet below the 300°F threshhold of convection oven preparation temperatures as stipulated for this category.

The results of the trade-off analysis are available in Table II. The materials were initially screened for the requisite thermal parameters as described above. They then were subjected to a physical property comparison and rated according to established procedures.

The following section contains a description by material group, such as polypropylene, nylon, and polyethylene rather than discussing the individual material candidates. It is felt that the difference between specific physical properties within a group are not significant enough to warrant an isolated discussion of each material, and that individual differences are attributable to material formulations involving the addition or depletion of additives such as stabilizer, plasticizer, reinforcing agents, and other modifiers.

Polypropylene

Polypropylene is a member of the polvolefin group which is similar to polyethylene. It is considered the lightest of the major plastics in commercial use today with a specific gravity of 0.9. Production

of polypropylene is so similar to that of polyethylene that, with few modifications, the same machinery may be used in its production. It is a colorless, odorless thermoplastic material, possessing a high strength-to-weight ratio, tensile strength, stiffness, and surface hardness. Biaxially oriented polypropylene, compared to extrusion or cast polypropylene, offers much greater strength and toughness properties along with reduced gas permeations and water vapor transmission rates. Although both extruded and biaxially oriented materials offer a similar range associated with resistance to elevated temperature, only biaxially oriented polypropylenes display a strong endurance against lower temperature levels (P.P.B.O. -60°F; P.P.E. 0°F).

Of the four major fabricating processes - molding, extrusion, fibers and film-polypropylene provides industry with the highest volume of thermoplastic material that is used in large quantities.[6] As an engineering plastic, it competes very effectively with such materials as metals and natural fibers. Typical industry and commercial application include automotive and appliance components, upholstery fabrics, and home furnishings. Medical, pharmaceutical, and cosmetic producers and suppliers rely on polypropylene in their reusable and disposable packages and components, most notably closures, caps, and valve devices. As noted in Table I, Polypropylene, biaxially

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(6) Modern Plastics Encyclopedia, "Polypropylene", op. cit., pp. 98-100

oriented, coated, (PP-B.O.C.) differs from polypropylene, biaxially oriented, uncoated (PP-BO) only in its oxygen permeability properties.

This is evident due to a characteristic coating believed to be saran which is specifically designed as an oxygen barrier.

Hercules Inc. has developed in conjunction with Illig Machinery through FMC what they describe as a "solid phase pressure forming" method for the production of biaxially oriented polypropylene containers.

Nylon 12, 11, 6/6

The term "nylon" is accepted as the synonym for synthetic polyamides. There are two groups of nylons based on chemistry and structure with each specific type identified, numerically. One group of polyamides is produced from amino acids and its derivative contain a single number, such as Nylons 6, 11, and 12. These numbers identify the number of carbon atoms in the monomer chains. Similarly, the second group of nylons are produced from diamines and dibasic acids and consequently are individually identified by two numbers, such as nylon 6/6.[7]

(7) Billmeyer, op cit., pp. 386-388

The available data as may be noted in Table III and as evaluated in Table I show these three nylon materials quite comparable in strength and toughness properties to include thermal resistance to degradation below -40^{0} and to 250^{0}F. Water vapor transmission rates indicate nylon 12 is best, followed by nylon 11, then 6/6. Oxygen permeation rates for nylon 11 and 12 are "poor" with nylon 6/6 as possessing good barrier properties. As shown in Table I, ranking order of these three nylons, in descending order, nylon 12, 11, 6/6. Generally, nylons are considered as an engineering material. They have found wide application in many areas such as automotive and appliance parts and accessories, electrical and electronics component and support devices where temperature, chemical, and flammability resistance are prerequisites in conjunction with high property strength and toughness. Other industrial applications include machinery gears, cams, bearings, sprockets, rollers, and pulleys. Nylon products are diversely employed throughout industry and consumer use.[8] As previously mentioned, nylon film has made a successful entrance into the consumer kitchen in such form as "boil-in-bag" and "bake-in-bag" ovenwrap products.

<u>Polyethylene: High Density Polyethylene (HDPE), and Medium Density Polyethylene (MDPE), and Low Density Polyethylene (LDPE)</u>

ASTM defines LDPE as 0.910 to 0.925 g/cm^3, MDPE as 0.926 to 0.940, and HDPE as 0.941 to 0.965. Polyethylene is produced by the

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(8) <u>Modern Plastics Encyclopedia</u>, "Nylon", <u>op. cit</u>., pp 54-55

polymerization of ethylene gas into large polymer chains.[9] Low and medium density materials result from a process involving high pressure and temperatures. Conversely, high density polyethylene is produced by a different process requiring ambient temperature and pressure.

The majority of low and medium density materials are produced in film and sheet form. It is flexible, light weight, provides good transparency in thin film, possesses excellent water vapor impermeability characteristics, and is one of the lower priced plastic materials currently available. Additional applications are seen in injection molded parts for toys, closures, and containers. Extrusion coating of paperboard containers, such as those used in milk cartons have found favorable and widely accepted use.

High density polyethylene is less flexible than low and medium density polyethylene, provides greater barrier properties than LDPE and MDPE, and is translucent in its normal state. Unlike LDPE and MDPE which may be 50-60% crystalline solids containing many branched chains in their structures, high density polyethylene is a highly crystalline polymer (90%) containing few side chains.[10] This structural property offers increased tensile strength, hardness, and water vapor barrier properties over the less dense materials.

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(9) Ibid., p. 82

(10) Billmeyer, op. cit. pp 379-386.

High density polyethylene has found its greatest application in injected blow molded products such as bottles and other hollow products produced by this technique. Other applications for this material include those similar to the low and medium density product.

Polyester 1,4 Cyclohexylene Dimethylene Terphthalate/isophthalate (PCDT)

Typical crystalline polyesters possess excellent resistance to solvents, chemicals, thermal extremes, and they provide excellent properties of strength and toughness. However, Eastman Chemical Company is producing an amorphous transparent thermoplastic polyester material design specifically for packaging application. It is designated as PCDT (1,4 cyclohexylene dimethylene terephthalate/isophthalate) copolymer. Its advantages over classical polyesters is its ability to be deep drawn and easily heat sealable.[11]

Eastman Chemical Products, Inc., identifies this material as "Tenite Polyterephthalate 7DRO. Additional material information is available in their materials bulletin MB-46C entitled "Tenite Polyterephthalate."

Polystyrene: Chrystal, Impact, and Acrylonitrile-butadiene-styrene (ABS)

Crystal polystyrene is crystal clear yet quite a brittle plastic. It is considered one of the least costly plastic materials currently available. When crystal polystyrene is combined with acrylonitrile and

(11) "Tenite" Polyterephthalate 7DRO," Eastman Plastics Material Bulletin, MB-46C.

rubber, acrylonitrile-butadiene-styrene (ABS) is produced. Impact polystyrene results from the addition of rubber to crystalline polystyrene.[12] Another valuable product of crystalline polystyrene is that of foam P.S. Many applications of this product are apparent in packaging. Besides typical uses as food containers-like egg cartons, foam cups, and the like, polystyrene foam plays a predominant role in shock and vibration interpack cushioning material.[13]

Crystal and impact polystyrene maintain a dominant position as packaging materials over ABS. Impact P.S. with the inclusion of rubber provides greater toughness and durability through the improvement of its elongation property over that of the more brittle crystalline form. ABS by itself is industrially and commercially applied as an engineering plastic. There are some packaging products of this material available, but they center primarily around an engineering application where strength and durability are of immediate concern.[14] The primary disadvantage inherent with these three materials are their poor gas and water vapor transmission barrier properties.

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(12) Billmeyer, op. cit., pp. 404-409

(13) Modern Plastics Encyclopedia, "Polystyrene", op. cit. pp. 102-103

(14) Billmeyer, op. cit., pp. 404-409

Clear plastic cups and meat trays are but two applications of crystal P.S. Impact P.S. is seen in toys, appliance and hardware components, in addition to various packaging products. ABS products are quite widely accepted for automotive, appliance and related hardware components. Durable items such as football helmets and electrical appliance housings employ ABS because of its superior strength and toughness.

Polytrifluorochloroethylene (PTFCE)

Polytrifluorochloroethylene (PTFCE) is produced by 3-M Company and Allied Chemical under the trade names of Kel-F and Plaskon CTFE, respectively. PTFCE has excellent resistance to heat and cold (-400 to 300°F), is crystal clear, flexible, and nonflammable. Water vapor transmission rates are considered excellent while gas transmission properties are less so. PTFCE displays excellent chemical resistance and, therefore, has many applications in valves, fittings and pipe seals, "O" rings and gaskets. Closures for highly corrosive product containers are made of this material. Additionally, PTFCE may be found in electrical and electronic components due to its exceptional electrical and thermal properties.[15]

Polycarbonate

Polycarbonate is another engineering plastic. It provides toughness, dimensional stability, a wide range of thermal resistance, good electrical properties, and high impact strength even at low temperatures.

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(15) Modern Plastics Encyclopedia, "Fluoroplastics", op. cit., p. 32

Parts made from polycarbonate are usually subject to sudden impacts or heavy blows, such as appliance housing, automotive parts and accessories, and hardware components. Due to its excellent weatherability, it has found many uses in outdoor application, such as exterior lighting and break resistant tail-light lenses.(16) Polycarbonate's weak area is that of barrier properties. Both oxygen permeability and water vapor transmission rates are high. Because of its poor barrier properties, coupled with less costly materials more applicable to food packaging, polycarbonate will presumably maintain its status as primarily an engineering material.

C. Extent of Interchangeability Permitted by Commercially Available Containers

Information as to the extent of interchangeability permitted by commercially available containers based on size and sealing ability employing a single package machine was investigated. Information obtained from Anderson Brothers Manufacturing, Rockford, Illinois, and Dake Corporation*, Grand Haven, MI would indicate that interchangeability involving containers of different perimeter dimensions would require a complete mechanical changeover of parts with

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(16) Modern Plastic Encyclopedia, "Polycarbonate", op. cit., p. 72

* Dake Corporation is the machinery firm supporting Riviana Foods rigid vinyl coated aluminum foil frozen food package hermetic seal closure system.

an estimated period of twenty-four hours. Lidding machines of this configuration and working principle such as the Anderson Brothers Model 931-32 possess specific size container pockets which are mechanically conveyed by a precise fixed pitch chain. A mechanical changeover that would satisfactorily accept and transport a different size container would require a complete change of these parts. Parts costs for such a change was estimated to run between $5,000.00 and $10,000.00 by Mr. Lee Kenke of Dake Corporation.

There exist at least two possible solutions which may circumvent such an expensive and time consuming changeover. The first approach would accomplish a volume change by varying the depth of the container. As long as the perimeter dimensions are not altered, there will be no requirement for a mechanical changeover. A second solution would incorporate a constant perimeter as the above concept, yet would vary the containers' intracompartment from one to a modulated two or more. In effect, the entree size container may be substituted by a two-compartment container of the same parameter which in this example would allow for two side dish items. This is considered quite a feasible approach because heat sealing is accomplished by a heated roller. This roller precludes the need for any parts modification as associated with changing sealing dies.

D. Recommendations for Two Combinations of Containers and Heat Sealable Lidding Material

Recommendations as to which two combinations of containers and heat sealable lidding material for each category (metallic and nonmetallic) will provide the best total food package is presented. Pertaining to the requirements of this investigation, there are four possible material combinations which may be applied to categorize lid/container relationships. They are metallic base lids to metallic base containers; metallic base lids to nonmetallic base containers; nonmetallic base lids to metallic base containers; and nonmetallic base lids to nonmetallic base containers. Any combination involving the use of a metallic base material will nullify its use during microwave food preparation. Therefore, it is assumed that all materials discussed herein will be subjected to convection oven food preparation procedures.

Hermetically sealed semirigid to rigid packages containing entree size frozen food products are a fairly recent innovation. With the increasing advent of new and improved materials, this facet of packaging will continue to be a dymanic progression of food packaging benefits, meeting industry's needs and satisfying, ultimately, consumer demands. The following suggestions for type of material to be used for lid/container variations are based upon the investigation conducted for this report. It should be further noted that

nonmetallic base lidding material thickness will primarily be a function of water vapor and oxygen barrier properties as associated with desired storage life.

D-1 Metallic base lids/metallic base containers

The aluminum foil vinyl coated lid and container combination appears to be the best. The containers would be approximately 4 to 5 mils aluminum foil with about 0.5 mil thickness of a vinyl coating applied to the inside. The lidding material of similar construction would be about 1.5 to 3 mils aluminum foil containing a vinyl coating of about .25 mil thickness. As previously mentioned, this particular construction and container design is being successfully used by Riviana Foods, Houston, Texas.

D-2 Metallic base lids/nonmetallic base containers

This category of material lid/container relationship indicates that a coated aluminum foil lid in combination with a 15 to 20 mil thickness of Union Carbide's polysulfone product "Udel" would satisfactorily provide the physical property parameters required here. The application of "Udel" here is primarily due to its resistance to elevated temperatures (400°F) and its commercial availability. This is opposed to other exotic materials which, although qualified, are still in the embryonic stages of development. The lidding material would be similar to that discussed above only incorporating a coating material acceptable for heat sealing to the polysulfone container.

D-3 Nonmetallic base lids/metallic base containers

It is suggested that this combination include a 4 to 5 mil aluminum foil coated container in combination with 3M Company's polyester oven film material of 1.5 to 3 mils thickness. Polyester oven film is experiencing commercial usage in various school lunch programs where unit menus are prepared and packaged in advance for convection oven thermal preparation prior to dispersement and consumption. Additionally, polyester possesses barrier properties exceeding those of similar qualified materials.

D-4 Nonmetallic base lids/nonmetallic base containers

Subscribing to the assumption that temperatures generated by a convection oven will flounder close to 350°F, Union Carbide's polysulfone product as a food container employing a coated polyester oven film closure ranks the highest of all the commercially available alternatives of this category. Coated polyester oven film as mentioned above is chosen in lieu of "Udel" material closure because of its commercial availability and its reputation of performance. Container material thickness should be in the range of 15-20 mils with closure material from 1.5 to 3 min.

In conclusion, mention should be made once again to Keyes Fibre Company's "Kysystem." This system is a proven one which employs a vinyl impregnated fibreboard formed container in combination with a polyester oven film closure. Due to its poor barrier

properties, this system would have to include a secondary package made of an impermeable material. Besides its physical resistance to elevated temperatures, its costs and disposability should justify further investigation.

SUMMARY

Tabulated results of the trade-off data are provided in Table I. The order in which the thirteen materials are listed is the order of evaluation as may be noted by total score. The majority of these materials are used primarily as engineering plastics. This is due to their inherent strength and toughness, inertness to chemicals and solvents, and wide range of thermal resistance. With the exception of coated biaxially oriented polypropylene and nylon 6/6, the remaining eleven materials possess poor oxygen impermeability properties. The general profile for water vapor transmission is that of moderate to good. Ratings for heat sealability are excellent except for the more dominant engineering plastics of nylon, polycarbonate, PTFCE (Kel-F) and ABS.

Estimated per unit raw material costs for a container of 6 x 4 x 1.5 inches @ 18 mil, made of these materials are as follows:

Polypropylene	3-4¢
Nylon	20-22¢
Polyethylene	2-3¢
Polyester	11-12¢
Polystyrene	2-3¢

PTFCE (Kel-F)	$4.00-6.00
Polycarbonate	6-17¢
ABS	3-4¢

These quotations are considered to be approximate estimates and only pertain to the raw material, based on $/lb, which would physically be required for the above size container.

Although all of these materials are considered engineering plastics, the spectrum of their applicability is much greater than those materials of the preceeding cateogry. The range covers for practically 100% engineering usage as with polycarbonate and ABS to substantially light usage as with low and medium density polyethylene and crystalline polystyrene. These latter materials are employed more in packaging either as a primary package or as an interfacing component.

SECTION II

PACKAGING MATERIALS CURRENTLY USED IN FROZEN FOOD INDUSTRY

II. MATERIALS CURRENTLY USED IN FROZEN FOOD INDUSTRY

A survey of material producers, suppliers, converters, and frozen food producers was conducted as part of this project. A telephone interview technic was employed due to the different and distant geographical locations of the various respondents. Targeted organizational interviews included research and development personnel, project managers, or technical representatives. Interview questions circumscribed the present and future availability of candidate materials and products which may be related or associated with frozen food packaging. This design was intended to reveal current trends in frozen food packaging along with future projections generic to this area. Furthermore, it was anticipated that information solicited from material producers and suppliers would provide a foundation in support of the trade-off analysis of Section I and possibly expose any fruitful research and development efforts affecting frozen food packaging.

Interviews conducted with representatives of frozen food producers were designed to acquire knowledge of their packaging problems, solution to those problems, and technics unique to their specific mode of operation. It was further assumed that this producing element would be an excellent informational source and thereby provide a barometer for future frozen food packaging designs, concepts, and marketing trends.

Sixty-two organizations represented by eleven frozen food producers, forty-seven material producers and suppliers, and four distributors of microwave ovens were surveyed. An alphabetical list of these representatives is offered as Appendix "B".

In adherence with the objectives and scope of this project, an itemized offering of information by individual organizations will not be included as part of this report. Much of the acquired data is repetitive and/or common knowledge. It is, therefore, the intent here to generally summarize the data with a more involved discussion on information which is considered new or significant.

A. <u>Aluminum Foil Containers: The Industry's Staple</u>

Of the major frozen food producers surveyed who offer products which are designed to be reconstituted in their primary packages, all, with the exception of Riviana Foods, Inc., are using aluminum foil trays and tubs employing either a crimped foil or paperboard plug closure. Semirigid foil containers offer a number of advantages which justify its popularity among frozen food producers. In addition to its inherent protective properties, the consumer may heat, with the exception of microwave oven, the food product in its container, serve, consume, and dispose of with little , if any, after meal clean-up. The brightness, luster, and hygienic appearance of these containers provides an appealing attractiveness. Secondary uses of these

packages are evidenced most everywhere as flower pots, stove liners, reflectors for closet lighting fixtures, Christmas decorations, cooking medias, and whatever else an active imagination may think of, including reclamation.

Aluminum foil in gauges 0.0007 in. and above are considered impermeable to moisture and gases. Thinner thicknesses possess pinholes which attribute for some permeability. Joseph Hanlon in his book Handbook of Package Engineering claims:

> "The chance of finding one or more pinholes in a square foot of foil is about 15 percent at 0.0007 in. and 8 percent at 0.001 in. These pinholes will range in size from 0.0000001 to 0.00003 sq. in. In 100 sq. in. of 0.00035-in. foil, the total area of all the pinholes will be about 0.00004 sq. in."(18)

The year 1965 was the first year in which hermetically sealed aluminum foil/laminate containers, incorporating a heat seal closure, were introduced.(19) Hermetically sealed foil laminate containers are currently in wide use with applications not only in the packaging of food but also pharmaceutical and nonfood products as well.

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(18) Joseph F. Hanlon, "Film and Foils," Handbook of Package Engineering, 1971, pp 3-56.

(19) Ken H. Johnston, "Formed Rigid and Semirigid Aluminum Containers," Modern Packaging Encyclopedia, July 1969, pp 272-273.

Riviana Foods, Inc., Houston, Texas, currently is using hermetically sealed aluminum foil/vinyl laminate semirigid containers. Representatives from Riviana report that they are experiencing excellent results with this package. Line speeds are averaging 100 per minute with product shelf-life estimated to be 12-18 months. Discussions with representatives of Reynolds Metals and Alcoa, each offering similar foil products to include laminates, have provided assurance that laminate products have been successfully tested and proven for frozen food packaging applications.

Furthermore, as evidenced by Riviana Foods, Inc., production technology for filling and sealing containers made of these materials is currently available and in use.

The general theme for frozen food semirigid packaging, as established by this survey, is that there isn't really anything wrong with the foil containers; they have been used quite effectively; application is widespread; continued usage is historically supported by its availability, costs, and consumer acceptance; and with the two primary exceptions of increasing aluminum costs and prohibited microwave use, continued use as the staple container of this industry is projected.

B. Nonmetallic Frozen Food Containers: The Future

It is evident that aluminum foil containers are currently the staple package of the reconstitutable frozen food industry. However, there are

organizations which are concerned about the two primary exceptions to aluminum containers. Notably, the prohibited usage of microwave ovens is sounding a few alarms. There is an increasing number of microwave producers and, therefore, units available today and more expected tomorrow as technology continues to advance. Along with increased supply will soon follow greater public awareness and acceptance of microwave ovens. Until recently, few households could justify the cost of these ovens. However, as the availability of more units by more manufacturers coupled with technological progress continues, the unit price will fall - a phenomena basic to economic theory. Much of this country's creative cooking has been replaced by convenience food items designed and offered in serving portions of usually one meal. Man has become time conscious, hurried, and seemingly always late or behind schedule. Whatever the motivating factors, the average consumer has less time for anything, especially that of wasting undue time preparing a nutritious meal when short-cuts are readily available. With this, it has been suggested that increased household consumer usage of microwave ovens is prevalent, with staple acceptance being imminent.

This anticipation is far from revolutionary as may be seen in the many convenience food items offered by the food industry today and increased development work underway in this area. Representatives of Swanson's Foods indicate that they are presently exploring paper-board/polyester laminate containers as a feasible approach to future

marketing requirements. Earlier efforts involved the investigation of a polyester container with Du Pont. However, as mentioned in Section I (Polyester), development was terminated due to lack of market justification. Sara Lee, although presently employing similar frozen food packages as the rest of the industry, has been developing an innovative package. Periphery information indicates that it is of nonmetallic material and is designed for product reconstitution in either microwave or conventional ovens.

Night Hawk Foods, Inc. has been investigating a paperboard/vinyl impregnated container produced by Keyes Fibre. It is presently being used in some school lunch programs. These containers may be heat sealed with a polyester oven film produced by the 3-M Company. The paperboard is especially treated to withstand elevated temperatures generic to convection ovens and food preparation. The impregnation of the paperboard fibers with vinyl offers an additional advantage of decreasing absorbance of oils and water. Although water vapor and gas transmission are severe disadvantages of this container, the incorporation of an impermeable barrier film as a secondary package would provide the supplementary barrier protection for a system that would satisfy the parameters outlined in this project.

Union Carbide, as discussed in Section I, has a commercially available polysulfone product which has been developed and successfully

tested for thermal extremes associated with frozen food packaging and elevated temperatures of reconstitution (-60^{o} to $340^{o}F$). "Udel" is the trade name of this material and containers of which may be formed by conventional thermoforming methods. Additionally, "Udel" containers may be heat sealed with either like material, coated polyester oven film, or coated aluminum foil. Unfortunately, oxygen permeability and water vapor transmission rates are considered to be fairly high. This would require an impermeable secondary package similar to that alluded to for Keyes Fibre's vinyl impregnated paperboard product.

Containers made of "Capratherm 75" and its lidding material by Polycoatings of Chicago have Allied Chemical representatives excited. As mentioned in Section I, Allied Chemical is currently field testing a white pigmented, 17 mil, semirigid tray as their answer to frozen food packaging with end use reconstitution allowable in either a microwave or conventional oven. Representatives claim thermal resistance to temperatures below $-40^{o}F$. The lidding material is applied as a pressure-sensitive seal and not a thermal heat seal. Adhesive tack is not affected by water and the closure may be simply and easily reapplied. It has been field tested extensively over a 14 month period during which time more than 10,000,000 meals were successfully packaged, frozen, shipped, stored and reheated. This lidding material automatically vents moisture at reheat temperatures.

It is self-sealing, resealable, and provides superior protection for maintaining product integrity. The application of this closure does not require expensive heat seal machinery. Furthermore, speeds are claimed to be virtually unlimited with product seal failures said to be low enough to justify any cost differences between conventional heat seal film and these pressure sensitive lidding films.[25]

Summary

Section II contains the results of a survey conducted to determine current and future frozen food packaging trends, concepts, and designs. Information acquired by this survey shows aluminum foil semirigid containers employing either a crimped foil or paperboard plug cover as the industry staple. General sentiment is running fairly strong in support of its continued use. However, additional information has revealed some strong innovative research and development work on competitive nonmetallic products.

There are two primary disadvantages associated with aluminum foil containers. They cannot be used for heating foods in microwave ovens, and their increasing material cost. To define total cost would involve not only cost of raw material production but identifying values for the energies spent in its production, distribution, and consumption. Whis would include the ecological impacts

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(25) Ross Llewellyn, Inc., Advertising-Public Relations-Marketing Counsel, 222 South Riverside Plaza, Chicago, Ill., "News release for TI TAC CORP.", Feb. 27, 1974.

associated with each step from initial mining through after use disposal. An underlying assumption to this total cost element indicates that this material will cost progressively more, if not already, than many of the nonmetallic alternatives once in final product form. As for microwave oven acceptability, generic to aluminum foil are its reflective properties which restrict sufficient penetration of microwave energy to efficiently and effectively heat a food product. Therefore, investigations have been launched in the field of nonmetallic materials to satisfy the physical parameters of frozen food packaging and the nonreflective requirements of microwave energy. The survey indicates that there is current development work on a nylon based container by Allied Chemical Company that will offer all the properties desired for a frozen food container and subject to either microwave or conventional oven preparation temperatures. Nonmetallic products which have survived this development phase are Keyes Fibre paperboard/vinyl impregnated container "Chinet Ovenware" and Union Carbide's polysulfone produce "Udel." Both products offer physical properties conducive to this category. Although "Chinet Ovenware" contains worse barrier properties than containers made of "Udel", both carry poor oxygen permeability and water vapor transmission ratings. This disadvantage could be improved by incorporating an impremeable, secondary package which is not unusual for multiunit or bulk packaging.

The 17 mil semirigid tray with the pressure sensitive lidding material which has been field tested by Allied Chemical deserves serious consideration for future Air Force Applications in the frozen food area.

CONCLUSIONS

Conclusions

Section I focused on a material trade-off analysis in which qualifying non-metallic polymer materials were evaluated by physical properties and accordingly ranked into two categories. The first category contains those materials applicable to either microwave or convection oven extremes. The second category contains those evaluated materials considered applicable to microwave oven food preparation only. The qualifying criteria was thermal resistance to elevated temperatures with category I 300°F and above, and Category II being 185° to 299°F.

Five materials qualified as acceptable under the requisites for Category I. These materials are engineering plastic which possess excellent thermal resistance to temperatures below -40°F and in excess of 300°F, good strength and toughness characteristics, and somewhat less favorable gas and water vapor barrier properties. Evaluation for materials in Category II show thirteen potential materials. Although the thermal properties were lower than those of Category I, the majority of these materials offer similar physical properties as those in the first category. These data are illustrated in Table II, which contains a composite evaluation of all the materials. It is evident that there is not a significant difference between those evaluated materials of Category I and those of Category II - except that the first group has greater resistance to temperatures above 300°F. Additionally, the estimated individual raw material cost indicates that the materials of Category II cost less than those of Category I.

APPENDIX A

TRADE-OFF ANALYSIS SCORING CRITERIA

TRADE-OFF ANALYSIS SCORING CRITERIA

The initial mode of screening was an investigation of commercially available materials and their physical properties. The primary objective was to obtain a satisfactory heat seal withstanding a -40°F environment.

Heat sealing is simply a welding process wherein two like materials are molecularly combined by catalytic thermal energy. It is generally understood that these joined areas containing the sealing width offer greater resistance to structural failure than the material itself. Therefore, it was assumed that any plastic material which satisfactorily resists failure at or below -40°F (ASTM test method D759-66) was an acceptable candidate for further material screening.

A second criteria of evaluation was candidate materials adhering to FDA regulations governing materials used in primary food and drug packaging. In conjunction with this stage, all available information pertaining to aluminum foil and commercially available adjunct laminates was examined to identify noncompatible material of conversion. Those materials surviving the first levels of screening criteria, resistance to failure at or below -40°F, and meeting FDA approval, were grouped as being aluminum foil based or nonaluminum foil based. The candidate materials of each group were examined and evaluated through a trade-off analysis employing an assigned value system correlated with the degree of importance associated with inherent criterion of evaluation. Criterion definition and scoring were as follows:

Criteria Scoring:

1. Resistance to cold as defined by ASTM test method D759-66.

less than -39°F	0 Points
-40° to 50°F	3
more than -50°F	5

2. Heat seal temperature range

less than 215°F and more than 400°F	1
350° to 400°F	3
215° to 350°F	5

3. Oxygen permeability rate (cc/100in^2/mil/24hrs/atm/@25°C)

greater than 12.1	1
8.6 to 12.0	2
5.1 to 8.5	3
2.6 to 5.0	4
less than 2.5	5

4. Water vapor transmission rate (g/100in^2/24hrs/mil/@37.8°C)

greater than 6.10	1
1.51 to 6.0	2
0.71 to 1.50	3
0.21 to 0.70	4
less than 0.20	5

5. Strength (tensile strength p.s.i.)

less than 600	1
600 to 1000	2
1000 to 3000	3
3000 to 9000	4
greater than 9000	5

6. Toughness was defined by the area under a materials' stress-strain curve which represents the work required to fracture a test piece.

poor	1
fair	2
moderate	3
good	4
excellent	5

7. Stiffness was defined by a material's modulus of elasticity.

low modulus of elasticity--soft	3
medium modulus of elasticity--semirigid	4
high modulus of elasticity--rigid	5

8. Resistance to heat as defined by ASTM test method D759-66

less than 200°F	1
200 to 299°F	3
300 +	5

The criteria were further collected into three groups on the basis of relative importance. Each criteria was assigned a rank relative to all of the other criteria. The weighting factor of each criteria in a group was the average rank of all of the criteria in the group (.5 are rounded up, i.e., 6.5 = 7).

Criterion	Weighting Factor	
Resistance to cold °F	7	
Heat seal temperature range	7	Group I
Oxygen permeability	7	
Water vapor transmission rate	7	
Strength	4	Group II
Toughness	4	
Stiffness	2	Group III
Resistance to heat °F	2	

The weighted scores were obtained by multiplying the raw score awarded by the weighting factor.

Physical Property Trade-off Data

Criteria		I	II	III	IV	V	VI	VII	VIII	TOTAL
Weighting Factor		2	2	4	4	7	7	7	7	
Material:	A									
	B									
	C									
	D									

TOUGHNESS EVALUATION CRITERIA

	Tensile Strength (x 10^3 psi)	% Elongation (%)	Tensile Modulus (x 10^5 psi)
Low	0-2.5	0-60	0.0-1.75
Medium	2.6-9.0	61-200	1.76-4.50
High	9.1 +	201 +	4.51 +

TOUGHNESS CLASSIFICATION

	Tensile Strength	% Elongation	Tensile Modulus
Poor	Low	Low	Low
	Low	Low	Med.
Fair	Low	Med.	Low
	Low	Med.	Med.
	Low	High	Low
Moderate	Med.	High	Low
	Med.	High	Med.
	Med.	High	High
	Med.	Low	Med.
	Med.	Low	High
	Med.	Med.	Med.
	High	Low	Low
Good	High	Low	Med.
	Med.	Med.	High
	High	Low	High
	High	High	Med.
	High	Med.	Med.
Excellent	High	Med.	High
	High	High	High

APPENDIX B

FROZEN FOOD PRODUCERS
PACKAGING MATERIAL PRODUCERS AND SUPPLIERS
MANUFACTURERS AND REPRESENTATIVES OF MICROWAVE

FROZEN FOOD PRODUCERS

1. Banquet Foods Corporation
St. Louis, Missouri
(314) 436-5000
Mr. Jim Grace
(Frozen Food Pkg.)

2. Birds Eye
General Foods Corporation
White Plains, New York
(914) 694-2500
Mr. Jim Olney
(Frozen Food Pkg.)

3. Dressel's Bakeries
Chicago, IL
(312) 434-5300
Mr. Evans
(Frozen Food Pkg.)

4. Green Giant Food Services Div.
La Suer, Minnesota
(612) 665-3515
Mr. Bob Koktavy
(Frozen Food Pkg.)

5. Libby
Chicago, Illinois
(312) 341-4111
Mr. Harris
(Frozen Food Pkg.)

6. Night Hawk Foods
Austin, Texas
(512) 444-4781
Mr. Johnny Hyde
(Frozen Food Pkg.)

7. Pillsbury Company
St. Paul, Minnesota
(612) 330-4663
Mr. John Selvic
(Frozen Food Pkg.)

8. Riviana Foods, Inc.
Houston, Texas
(713) 529-3251
Mr. T. Bedell
(Frozen Food Pkg.)

9. Sara Lee Foods
Dearfield, Illinois
(312) 945-2525
Mr. Jim Hildebrant
(Frozen Food Pkg.)

10. Stouffer Foods Company
Solon, Ohio
(216) 248-0700
Mr. Hugh Wahl
(Frozen Food Pkg.)

11. Swansons, Campbell Soups
Camden, NJ
(609) 964-4000
Mr. T.H. Terwilliger
(Frozen Food Pkg.)

12. Swift & Company
Oak Brook, Illinois
(312) 325-9320
(Frozen Food Pkg.)

PACKAGING MATERIAL PRODUCERS AND SUPPLIERS

1. Adell Plastics, Inc.
   Baltimore, Maryland
   (301) 789-7780
   Mr. Lee Major
   (Nylon 6/6 + 11)

2. Albis Corporation
   Houston, Texas
   (713) 623-0380
   Mr. Herb Eller

3. Allied Chemical
   Morristown, New Jersey
   Plastics Div.
   (201) 455-4064
   (PVC/A, E-CTFE)

4. Allied Chemical
   Morristown, New Jersey
   Fiber Div.
   (201) 455-2151

5. Allied Chemical
   Morristown, New Jersey
   (201) 455-2361
   Mr. Julian Kushnich
   (Frozen Food Tray)

6. American Can
   Dallas, Texas
   (214) 351-3781
   Mr. Bill Howorth
   (Frozen Food Pkg.)

7. American Hoechst
   Bridgewater, New Jersey
   (302) 571-6011
   Mr. Ditmann
   (PVC-N.P.)

8. Belding Ind.
   New York, New York
   (212) 244-6040
   (Nylon 800, 600, 300)

9. Borden Chemical
   Livingston, Massachusetts
   (617) 537-1711
   Mr. Elliot Linsky
   Dr. Gene Skeist

10. Borden Chemical
    Columbus, Ohio
    (614) 225-4000
    Mr. Bob Zookawski

11. Borg-Warner Chemicals
    Parkersburg, W. Va.
    (304) 485-1771
    Mr. Leon Goff
    (ABS)

12. Cadillac Plastic & Chemical Co.
    Houston, Texas
    (713) 928-2581
    Mr. Wayne Beth
    (Pkg. Mat.)

13. Commercial Plastics & Supply
    Corporation
    Houston, Texas
    (713) 923-7795
    Mr. Art Swanson

14. Container Corporation of America
    Houston, Texas
    (713) 782-3625
    Mr. Jack Jarrell
    (Pkg. Material)

15. Cryovac Div., W.R. Grace & Co.
    Duncan, S.C.
    (803) 439-4121
    (PVC/EVA)

16. Diamond Shamrock
    Cleveland, OH
    (216) 694-5323
    Mr. Al McDonald
    (PVC/A)

PACKAGING MATERIAL PRODUCERS AND SUPPLIERS (CONTINUED)

17. Dow Chemical Company
Midland, Michigan
(517) 636-3746
Mr. Chester Davis
Mr. Russ Butler
(PVDC/VC)

18. Dow Chemical Company
Midland, Michigan
(517) 636-1212
Dr. Bob Clark
(Polyester/Saran Coated Tray)

19. Du Pont de Nemours, E.I. & Co.
Wilmington, Delaware
Technical Information
(302) 774-2421
Mr. Corstorphne
Mr. Mitch Kyanka
(Nylon 6/6, TFE)

20. Du Pont
Wilmington, Delaware
Experimental Station
(302) 774-2582
Dr. Fred Gander
(Polyester Trays)

21. Du Pont
Wilmington, Delaware
(302) 999-3412
Mr. Nagle
(Mylar (Polyester))

22. Eastman Chemical Products, Inc.
Kingsport, Tennessee
(800) 251-0351 X5551
(615) 246-2111
Ms. Mabel Lawson
Mr. Hap Chandler

23. Ekco Products
Wheeling, Illinois
(312) 459-1500
(Pkg. Mat.)

24. Federal Paperboard
Montvale, New Jersey
(201) 391-1776
Mr. Bill Brown
Paperboard/Polyester Tray

25. Fluorocarbon Co.
Pinebrook, New Jersey
(201) 227-2600
(CTFE (KEL-F))

26. Hercules, Inc.
Wilmington, Delaware
(302) 995-3655
Mr. Russell D. Hanna
Mr. Leroy Robeson
(P.P. B.O.)

27. Horner Waldorf Corp.
St. Paul, Minnesota
(612) 645-0131
Mr. Rudi Faller
(Paperboard Trays)

28. Huntsman Container
Fullerton, California
(714) 870-6880
Mr. Joe Payne
(PS Foam Containers)

29. International Paper Company
New York, New York
(212) 490-6407
Mr. Paul Dearborn
(Paperboard Trays)

30. Keyes Fibre
Montvale, New Jersey
(201) 278-9500
Mr. Newt Hagger
(Fibreboard Tray-
Vinyl Impregnated)

PACKAGING MATERIAL PRODUCERS AND SUPPLIERS (CONTINUED)

31. Milprint Corporation
Milwaukee, Wisconsin
(414) 332-5800 Ext. 204
Dr. Lee Brazier

32. 3-M Company
St. Paul, Minnesota
(612) 733-1110
Mr. Dennis Dehan
(CTFE (KEL-F)

33. Monsanto
St. Louis, Missouri
(314) 694-1000

34. Monsanto
Springfield, Massachusetts
Technical Service
(413) 788-6911
Mr. Sted Herman

35. Plastics Inc.
St. Paul, Minnesota
(612) 227-7371
Mr. A.E. Colato
(Polyester (Thermoset))

36. Plastics Mfr.
Dallas, Texas
(214) 331-5435
Mr. Jim Forrester
(Melamine Trays)

37. Polycoatings of Chicago
Elk Groove Vilg., Illinois
(312) 956-6360
Mr. Fred Wolf
(Lidding Material)

38. Reynolds Aluminum
St. Louis, Missouri
(314) 726-5700
Mr. Bill Riggs
(Frozen Food Pkg. Mat.)

39. Rilsan Corporation
Glen Rock, New Jersey
(201) 447-3300
Mr. Bartley
(Nylon 11)

40. Stauffer Chemical Company
Westport, Connecticut
(203) 226-1511
Mr. Paul Raycop
(PVC)

41. Tetra Fluor Engineers
Warwick, Rhode Island
(401) 738-7550
Mr. Rainone
(TFE)

42. U.S. Industrial Chemicals Company
Houston, Texas
(713) 479-2873
Mr. Thompson (Sales)
(EVA)

43. U.S. Industrial Chemical Co.
Tuscola, Illinois
(217) 253-3311
Mr. Bill Cash
(Polymer Service Lab.)
(EVA)

44. Union Carbide Corporation
Southfield, Michigan
(313) 354-0800
Mr. Maleen (Sales)
(Polysulfone)

45. Union Carbide Corporation
Chicago, Illinois
(312) 496-4200
Mr. Dave Dallich
Film Pkg. Div.
(Fibrous Casings)

46. Union Carbide Corporation
Boundbrook, New Jersey
(201) 356-8000
(Plastic Research Laboratories)

PACKAGING MATERIAL PRODUCERS AND SUPPLIERS (CONTINUED)

47. Vistron Div., SOHIO
    Cleveland, Ohio
    (216) 575-4141 X-5823
    Mr. Jack Keating
    (Barex (HBNR))*

*HBNR High Barrier Nitrile Resin

MANUFACTURERS AND REPRESENTATIVES OF MICROWAVE

1. Amana Corporation
   Amana, Iowa
   (319) 622-5511
   (Microwave)

2. Litton Designer
   Houston, Texas
   (713) 526-3961
   Mr. Tommy Hubbard
   (Microwave (Litton))

3. Sharp & Whirlpool
   Edmondson Appliance Company
   Houston, Texas
   (713) 281-4293
   (Microwave (Whirlpool & Sharp))

4. Westinghouse
   Houston, Texas
   (713) 772-4603
   (Microwave (Westinghouse))

Section II presented the results of a survey conducted on material producers and suppliers and frozen food producers to determine current and future frozen food packaging trends, concepts, and designs. It was found that semirigid aluminum foil containers continue to dominate frozen food packaging. Furthermore, there is strong sentiment in support of its continued use. However, information acquired from the survey shows three nonmetallic products which may be offered as competitive alternatives to aluminum foil. Allied Chemical Company currently is field testing a nylon based product which offers all the properties desired for a frozen food container and applicable to either microwave or convection oven food preparation. Union Carbide is currently marketing a polysulfene product which has been successfully tested for this type of application. Keyes Fibre has available a paperboard/vinyl impregnated product which provides similar attributes as do the above two products with the exception of poorer barrier properties associated with the paperboard. If barrier properties are a serious threat at the lower temperatures, as it may be with the paperboard product, a secondary impermeable material could easily be applied in resolution of this problem.

Recommendations

A. Further investigation be conducted on the above discussed products offered by Allied Chemical (Capratherm 75), Union Carbide (Udel), and Keyes Fibre (Chinet Ovenware) to determine shelf life under specific storage conditions; the need for secondary and tertiary

packaging; unit quantities required; unit cost; and type and style of associated production equipment. Furthermore, if time permits, continued investigation on those materials contained in Categories I and II should be pursued.

B. If concerned only with the continued use of semirigid aluminum foil containers which may be hermetically heat sealed, contact Mr. Jerry Bedell, Riviana Foods, Inc., Houston, Texas, who was responsible for successfully implementing this type of production process.

C. If microwave oven usage is anticipated to be the sole food preparation medium, further investigation should be conducted on those materials contained in category II, of Section I to determine the most economic and efficient material available.

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